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Predicting Working Memory and Fluid Intelligence from Measures of Musicality

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PREDICTING WORKING MEMORY AND FLUID INTELLIGENCE FROM MEASURES OF MUSICALITY

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ABSTRACT

The relationship between musicality and cognitive abilities has been a popular topic in the media and among researchers over the last 25 years. Research has been inconsistent on whether musicality influences performance on non-musical complex tasks, such as measures of working memory and fluid intelligence. Inconsistencies regarding results between studies have arisen partly due to differences in sample and task selection, in addition to conflicting interpretations of results. Consequently, we conducted an individual differences investigation on the prediction of working memory (tonal, verbal, and visuospatial) and fluid intelligence by measures of musicality (formal years of musicality training, musical sophistication, melodic memory, and beat perception). Using correlational and regression approaches, the results showed that individual measures of musicality did not predict performance on each complex cognitive measure uniformly. These results suggest that relationships between musicality and cognitive abilities can be potentially influenced by measurement selection, and musical experiences and abilities underlie cognitive abilities differentially. Further exploration is needed to understand how and why these relationships occurred.

CHAPTER 1. INTRODUCTION

Psychologists have been interested in understanding how and why people differ for over a century. Over time, numerous psychologists have advocated for the integration of differential and experimental approaches in research (e.g., Cronbach, 1957; Cohen, 1994). Benton J. Underwood, an eminent experimental psychologist, stated that “individual differences ought to be considered central in theory construction, not peripheral” (Underwood, 1975, p. 129). Although some psychologists, such as behaviorist John Watson (e.g., Watson, 1913), have historically neglected differential psychology, individual difference research can provide insight regarding the processes and mechanisms underlying the human mind, brain, and behavior. On cognitive tests, it is undoubtedly clear that people differ in their abilities. Understanding how and why these differences occur are of importance to educational, health, military, and other diverse endeavors.

Working memory and fluid intelligence research are hallmarks of the utility of individual differences approaches. Working memory is “the ensemble of components of the mind that hold a limited amount of information temporarily in a heightened state of availability for use in ongoing information processing” (Cowan, 2016, p. 1159). Working memory is extensively studied partly because of its strong relationship with higher-order cognitive abilities (e.g., Cowan et al., 2005; Shelton, Elliott, Matthews, Hill, & Gouvier, 2010), such as reading comprehension (e.g., Daneman & Carpenter, 1980). A benchmark of working memory research is that people with higher scores on measures of working memory capacity perform significantly better than people with lower scores on a variety of complex cognitive tasks (e.g., Hambrick, Kane, & Engle, 2005). The same empirical finding is observed with fluid intelligence, which is the ability to reason, solve novel problems, and identify patterns (Cattel, 1943). Fluid intelligence performance generalizes to other mental tasks, despite large variations between measures, including working memory (e.g., Kane et al., 2004). Poor performance on working memory and fluid intelligence measures can be a risk factor for psychopathologies such as ADHD (e.g., Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) and schizophrenia (e.g., Blair, 2006). Consequently, individual differences in working memory and fluid intelligence both have theoretical and practical significance.

There is growing interest regarding the relationship between musicality, working memory, and fluid intelligence. Musical activities, such as playing an instrument and singing, can undoubtedly be cognitively demanding. However, it has been unclear if developing skills in a music-related activity has a far-transfer effect on complex cognitive abilities (e.g., Schellenberg, 2004; Moreno et al., 2011) or if instead, complex cognitive abilities are selective of musical ability (e.g., Meinz & Hambrick, 2010; Swaminathan, Schellenberg, & Khalil, 2017). The effectiveness of current approaches to improve working memory capacity, such as being trained over a period of time on working memory tasks (e.g., Jaeggi et al., 2010), with a subsequent far-transfer improvement to other aspects of higher-order cognition, has been controversial (e.g., Shipstead, Redick, & Engle, 2012; Redick et al., 2013). Therefore, the interest in the relationship between musicality, working memory, and fluid intelligence partly stems from the practical significance of discovering a novel, effective mechanism to improve complex cognitive abilities.

Thus, the goal of the present study was to investigate the prediction of individual differences in working memory and fluid intelligence by measures of musicality. This investigation provided a better understanding of how musical training, experiences, and abilities are related to complex cognitive abilities and provided insight on how measurement selection can influence those respective relationships.

What are Non-musicians and Musicians?

Studies investigating the relationship between musicality and cognitive abilities frequently compare performance between musicians and non-musicians on a set of cognitive tasks. Thus, one of the first steps in experiment construction is setting criteria to differentiate a non-musician and musician during recruitment and analyses. Criteria for non-musician and musician participants is not uniform in the literature. The most common variable used is the amount of years receiving formal musical training. Criteria for non-musicians is typically no or limited formal musical training (e.g., less than 2 years; Slevc, Davey, Buschkuehl, & Jaeggi, 2016). Criteria for musicians have fluctuated with varied requirements on the minimum amount of formal training (e.g., at least 5 years; Slevc et al., 2016; Swaminathan et al., 2017). Few studies are more selective regarding their musician criteria, including criteria for age when training began and hours of weekly practice (e.g., Franklin et al., 2008). The samples in which musicians are recruited have also varied. Some studies strictly used students studying music (e.g., Schulze et al., 2011), and others have allowed non-music majors such as psychology (e.g., Swaminathan et al., 2017). In analyses, the separation between musicians and non-musicians is frequently kept intact by conducting between-group analyses and seldom replaced by using formal years of training as a continuous variable. As a result, it can be difficult to compare results across studies due to a lack of uniformity in recruiting and analyses.

Additionally, formal years of training may be an imperfect measure to determine a musician or one's amount of musicality. Formal training can encompass a diverse range of experiences, such as a participating in a university wind ensemble or receiving private one-on-

one lessons with an instructor. This variable, alone, does not provide potentially relevant information, such as how much participants actively practiced and the age that training began. Consequently, the longevity of training may not be a clear indicator of being more musical. Additionally, it is possible for non-musicians to develop musicality without formal musical training. Non-musicians can implicitly learn tonal structures and other hierarchical strategies from mere exposure during musical experiences that can potentially enhance recall of musical information (e.g., Tillmann, Bharucha, & Bigand, 2000). Music's involved role in society presents opportunities for anyone to actively engage with music and develop musicality. Therefore, formal years of training, alone, could potentially be a flawed representation of participants' musicality.

A growing number of experiments investigating musicality and cognitive abilities have included measures of musical aptitude and behaviors to replace, or be used in addition to, formal years of training (e.g., Slevc et al., 2016; Swaminthan et al., 2017). Musical aptitude tests date back to Carl Seashore (e.g., Seashore, 1939), who published the first standardized battery of music aptitude tests. Seashore believed the physical properties of sound were the foundation of the psychological responses to music, and sensory abilities could predict musical talent (e.g., Seashore, Lewis, & Saetveit, 1956). Modern tests of musical aptitude mainly utilize same-versus-different paradigms that test melodic and rhythmic deviations. For example, the Advanced Measure of Musical Audiation (AMMA; Gordon, 1989) requires participants to differentiate rhythmic and pitch differences between two melodies. Thus, these differences are found in the same melodic context and participants must divide attention between rhythmic and tonal properties. The Musical Ear Test (MET; Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vusst, 2010) is similar to the AMMA but includes separate melodic and rhythmic subtests, and the melodic subtest focuses on both pitch and contour differences. Both the AMMA and MET use artificially created stimuli that could potentially negatively impact its ecological validity and is reliant on Western art (Müllensiefen, Gingras, Musil, & Stewart, 2014).

The Goldsmiths Musical Sophistication Index (Gold-MSI) improves on the previous tests by using melodic and rhythmic tests that incorporate a range of musical styles to better predict real-world listening behaviors (Müllensiefen et al., 2014). An additional sound similarity test is used to measure the ability to make musical judgments from sound information by taking a list of excerpts and combining them into four groups based on their relatedness. Furthermore, the Gold-MSI includes a comprehensive self-report inventory that unveils a diverse range of information on participants' musical behaviors and experiences. Over time, tests of musical aptitude and behaviors have progressed, becoming more reliable, and easier to administer. There is potential for these measures to continue their increase in usage and provide insight about the musicality of both musically trained and untrained participants.

Musicality and Working Memory

As mentioned above, consistency in the research methods investigating musicality and working memory has been mixed, as well as the outcomes. Tonal working memory has generally been under-researched in the working memory literature, but there are consistent findings of superior tonal working memory in musicians compared to non-musicians (e.g., Schulze, Dowling, & Tillmann, 2012; Talamini, Altoè, Caretti, & Grassi, 2017), with some researchers suggesting the existence of a special tonal working memory system in musicians (e.g., Berz, 1995; Schulze et al., 2011). However, evidence of superior working memory in other domains has been inconsistent (e.g., Schultz et al., 2011; Hansen et al., 2012; Slevc et al., 2016). Studies investigating the relationships between musicality and tonal, verbal, and visuospatial working memory will be discussed.

Schulze et al. (2011) tested verbal and tonal working memory performance between non-musicians and musicians in a recognition paradigm. fMRI was used to investigate the neuroarchitecture of tonal and verbal working memory during rehearsal. Musicians were college music students, and non-musicians were individuals with no formal training. Participants listened to sequences of 5 tones and 5 letters simultaneously presented. Before each trial, they were presented a visual cue of which domain (letter or tone) to focus their attention. After the sequence of stimuli, they were provided a rehearsal period, in which fMRI scans were conducted. Subsequently, participants were presented a test stimulus and had to make a present or absent judgement on whether the stimulus was presented in the sequence. Behaviorally, musicians significantly outperformed non-musicians in tone accuracy, but the groups showed no significant difference in letter accuracy. Results from the fMRI analyses indicated that both groups had overlapping core structures for both tonal and verbal working memory, but there was also evidence for different neural subcomponents. Notably, musicians had unique sensorimotor activity for tonal working memory compared to verbal working memory. The authors suggested the unique activity during tonal rehearsal, in addition to superior tonal accuracy, implicated a domain-specific tonal working memory system for musicians (e.g., Pechmann & Mohr, 1992; Berz, 1995) in models of working memory (e.g., multicomponent model; Baddeley, 1986).

Schulze et al. (2012) extended Schulze et al. (2011) by testing non-musicians and musicians on tonal and atonal sequences in a modified recognition paradigm. Knowledge of tonal structures could potentially explain superior performance by musicians. Eliminating the advantage could level performance between musicians and non-musicians, similar to verbal working memory. Therefore, backward presentations were incorporated on half of the trials. Backward presentations force participants to both maintain and manipulate the tones, which can potentially limit musicians from freely using knowledge of tonality. The procedure included making a same or different judgment between two sequences of tones. Each trial was either two tonal sequences or two atonal sequences. Half of the trials included a backwards presentation during the second presented sequence (e.g., a same trial during backwards presentation would be F, G, D, E, C and C, E, D, G, F). Sequence length was manipulated to test whether longer sequences lowered performance, similar to length effects found with verbal and visuospatial stimuli (e.g., Cowan, 2000). Thus, participants still judged whether two sequences of tones were similar or different. Generally, longer tonal and atonal sequences lowered performance for both groups during forward and backward presentations. Both musicians and non-musicians performed better on tonal than atonal sequences, with musicians performing the best during both sequences. This result suggested that non-musicians also have knowledge about tonal structures, potentially through implicit learning. The effect of tone structure disappeared in the backwards presentation. Although musicians outperformed non-musicians, there was no difference between tonal and atonal sequence performance for both groups. In conclusion, knowledge of tonal structure, alone, cannot explain musicians' superior tonal working memory performance.

Slevc et al. (2016) found that musicality is related to superior verbal and tonal working memory performance in an individual difference examination, partially conflicting with Schultz et al. (2011). Musicians in Slevc et al. were members of the university community with at least five years of formal musical training, and non-musicians had less than two years of formal musical training. There were a total of 48 musicians and 48 non-musicians. Participants completed a battery of executive function tasks, including auditory tone and visual letter n-back tasks of working memory. During the auditory tone n-back tasks, a series of tones were presented via headphones, and participants identified when they heard a pitch “N” tones previously. “N” could be a value of 1, 2, 3, or 4 positions. The visual letter n-back task had the same procedure but with visually-presented letters. The Ollen Musical Sophistication Index (OMSI; Ollen, 2006), which includes ten self-report questions, was utilized to measure musical experience and ability by computing a sophistication composite score between zero and 1000. The MET (Wallentin et al., 2010) was also utilized to measure musical aptitude with its melody and rhythm subtests.

Correlational analyses demonstrated that both melody and rhythm subtests in the MET had stronger correlations with the n-back tasks than the OMSI and were each statistically significant. The auditory tone n-back task had a statistically significant relationship with the OMSI, but notably the visual letter n-back did not. Similar relationships with each n-back task were found using a continuous variable of formal years of training, in which formal years of training had a statistically significant relationship with the auditory tone n-back task but not the visual letter n-back task. The correlations suggested that the approach to measuring musicality impacted the relationships found between musicality and updating executive function tasks, with the MET scores demonstrating the strongest relationship with the n-back tasks. It is unclear why these differences occurred but could presumably be due to the cognitive demands of the MET tasks. Additionally, the difference in performance across modalities were closely uniform, with each musicality measure having stronger relationships with the auditory tone n-back task than the visual letter n-back task. These correlational relationships support prior literature suggesting that musicality has more of a relationship with tonal working memory tasks than verbal working memory tasks (e.g., Schultz et al., 2011).

Slevc et al. (2016) then conducted multiple regression analyses with each executive function task as dependent variables. A composite musical ability score was computed with the performance on the melody and rhythm subtests of the MET and OMSI questionnaire, due to them being highly correlated with each other. The authors used the composite musical ability score as the key independent variable and controlled for age, socioeconomic status, handedness, and bilingualism. They found that the composite musical ability score significantly predicted each working memory task (i.e., the updating component of executive function), but not the other executive function tasks. Furthermore, the variance accounted for the auditory tone n-back task by musicality doubled the amount found for the visual n-back task, reflecting the prior correlational analyses. In conclusion, verbal and tonal working memory performance were found to be related and predicted by musicality, with musicality seeming to have the most influence on tonal working memory.

Franklin et al. (2008) also found that musicians had superior verbal working memory performance compared to non-musicians utilizing complex span measures of working memory. Participants completed a battery of cognitive tests, including the Operation and Reading complex span measures of working memory (e.g., Conway et al., 2005). These tasks require the maintenance of a sequence of stimuli while completing interpolated processing tasks, such as math operations (e.g., Operation span) and judgments on whether a sentence makes sense (e.g., Reading span). Franklin et al. used the following musician and non-musician criteria:

> Musicians began formal musical training at a maximum of age 10, had at least nine years of continuous musical training, currently practiced at least 15 hours a week, were current undergraduate or graduate music students, and rated themselves of having a sight-reading ability of 4 at least on a seven-point scale. Non-musicians did not currently play an instrument, had no history of instrumental training prior to age 10, never played an instrument for more than a year, and had a self-rated sight-reading of 1 on a seven-point scale (p. 356).

The study was administered across two phases with no more than 12 musicians and 13 non-musicians in each phase, and there were no differences on measure of fluid intelligence and SAT scores between the groups. Musicians scored significantly higher than non-musicians on Operation span. On Reading span, there was not a significant difference between the groups until a problematic subject was removed who had an absolute score of 0.

Finally, Talamini et al. (2017) conducted three meta-analyses that compared non-musician and musician's performance on long-term, short-term, and working memory tasks. The authors selected studies that had both adult musicians and non-musicians who completed memory tasks with verbal, visual, spatial, or tonal stimuli. The goal was to determine if musicians perform better than non-musicians on memory tasks, and if the stimuli chosen moderated the effect. "Musicians were defined as participants who had attended music conservatories or music schools, and non-musicians were participants who had little or no experience playing a musical instrument" (Talamini et al., 2017, pp. 3-4). In the working memory meta-analysis, selected tasks required a primary recall task with a secondary processing task, such as a complex span task, or a manipulation of the to-be-remembered stimuli, such as a backward span task. The authors decided to combine visual and spatial stimuli into a single visuospatial category due to a lack of studies examining them separately. The working memory analyses showed musicians outperformed non-musicians, and the type of stimuli used in tasks did influence the effect. There was a large effect with tonal stimuli, a moderate effect with verbal stimuli, and a small effect with visuospatial stimuli. Notably, there were 3 studies for tonal working memory, 13 for verbal working memory, and 3 for visuospatial working memory. Consequently, the lack of studies is to be taken into account with caution. Furthermore, the authors did not control for years of music training or other relevant musical variables because of the vast inconsistency in measuring musicality.

In summary, the relationship between musicality and working memory is largely unclear. While there have been consistent findings of superior tonal working memory in musicians, there are few studies that have actually used a tonal working memory measure. The recognition tasks used by Schulze and colleagues have not been assessed with other commonly utilized working memory measures, such as the complex span task. Furthermore, recognition based n-back tasks, which were used by Slevc et al. (2016), have been shown not to be interchangeable with other working memory tasks (e.g., Redick & Lindsey, 2013). There is a clear need for reliable, valid tonal working memory measures, especially measures that require the serial recall of tone sequences. Inconsistencies in the verbal and visuospatial working memory literature may stem from a lack of uniformity in measuring musicality, in addition to differences in sample selection. Talamini et al. (2017) stated "a shortage of information makes it impossible to disentangle whether or not musicians' enhanced performance is an effect of their music training" (p. 16). Slevc et al. combined their musicality measures into a singular construct, despite considerable differences in individual relationships among their n-back measures. In result, it is difficult to parse out how each individual aspect of musicality contributes to working memory performance, which would improve our understanding of how and why certain links between working memory and musicality appear. The emergence of comprehensive musical sophistication measures provides promise for detailed musical profiles of participants in future studies.

Musicality and Intelligence

The relationship between musicality and intelligence dates back to the belief of Galton (1883) and Spearman (1904) that sensory abilities, such as tone discrimination, could accurately predict intelligence. The 1990s saw an emergence of media attention regarding the rarely replicable Mozart effect (e.g., Steele, Bass, & Crook, 1999), which suggested that listening to music by Mozart could improve spatial reasoning (Rauscher, Shaw, & Ky, 1993). Additionally, interest in arts training having far-transfer effects towards intelligence was growing (e.g., Gardiner, 1996). There have been findings over time suggesting a relationship between musicality and intelligence (e.g., Schellenberg & Weiss, 2013). However, it is controversial whether music training actually causes improvements in intelligence, or rather if people with superior intelligence scores are more likely to become musicians.

Schellenberg (2004) directly investigated if music lessons could enhance intelligence in children. A large sample of children were separated into four conditions, which included two music education and two control conditions. The two music education conditions were keyboard and vocal training, and the two control conditions were drama instruction or no musical lessons of any kind. The music education conditions received music lessons for two years. The control conditions received either drama or no lessons for a year and keyboard training during the following year. Using two music education conditions would demonstrate the generality of music-specific instruction towards IQ enhancement. A control condition of drama instruction would demonstrate whether if the potential increase in IQ via music lessons is music-specific and not a product of general instruction. All four conditions had significant increases in full-scale IQ after music lessons when compared to scores prior to lessons. The magnitude of the increase was similar within the music education conditions and within the control conditions; thus, Schellenberg chose to combine the four conditions into music education and control groups to increase power for further analyses. The music education group had a significantly higher increase in IQ compared to the control group.

Steele (2005) criticized Schellenberg's decision to combine the four conditions into two groups, due to differences between the keyboard and vocal training. The vocal training, Kodaly, used non-musical techniques that made it theoretically different from the keyboard training. The data were reanalyzed using 4 separate conditions, and no significant differences were found. Furthermore, Black (2005) also criticized Schellenberg for not conducting statistical tests between each condition before combining the conditions into groups. Black reanalyzed the relationship between the drama and the two music instruction conditions by directly comparing scores and also the increase in magnitude via music lessons; no significant differences were found between the drama and music instruction conditions. The reanalysis also demonstrated that the increase in IQ was not music-specific. Nonetheless, there is a relationship between music lessons and intelligence, but its causal mechanism is still controversial.

Swaminathan et al. (2017) took a step forward towards determining why the relationship between musicality and a lower-level aspect of intelligence, fluid intelligence, exists. They tested whether the association between musicality and fluid intelligence is better explained by formal music lessons, musical aptitude, or both combined. The criteria used to select musicians and measure musicality have been inconsistent or lacked comprehensiveness; thus, it was unclear which aspect of musicality was responsible for the consistent results of high scores on various intelligence measures in musicians. They selected students from an introductory psychology course with either no musical training, which totaled 71 people respectively, or at least 5 years of formal music lessons, which totaled 62 people respectively. The number of formal years of training reported by participants was limited to music lessons outside of school and were primarily one-on-one lessons that included instrument training. This measure was used as a continuous variable of musical training. All participants completed a measure of fluid intelligence, and measures of musical aptitude, notably the melodic and rhythmic subtests of the MET (Wallentin et al., 2010). The authors also collected information about participants' socioeconomic status (SES), which included family income, father's education, and mother's education. First, Swaminathan et al. used multiple regression to test the prediction of fluid intelligence, musical aptitude, and music training by SES. They found that the model only significantly predicted music training, and only mother's education significantly predicted music training among the SES variables. Thus, only mother's education was used in the following analyses. Next, pairwise correlations found that music training was positively correlated with fluid intelligence, the melodic subtest, and the rhythmic subtest. The melodic and rhythmic subtests were positively correlated with each other and fluid intelligence.

They then used hierarchical multiple regression to predict fluid intelligence. On the first step, the predictor variables used were in the following order: music training, melodic subtest, rhythmic subtest, and mother's education. The model explained 22.68% of the variance, with little contribution by music training and mother's education, and a significant contribution by each music aptitude subtest. On the second step, they examined if music aptitude moderated the relationship between music training and intelligence. They added two interaction variables (melodic subtest and music training; rhythmic subtest and music training), which did not significantly improve the fit of the model, and neither variable was significant. However, both melodic and rhythmic subtests stayed significant. Lastly, they examined whether the relationship between music aptitude and intelligence was mediated by music training by using a bootstrapping estimation, which found no evidence for a mediation effect. Therefore, there was a nonsignificant relationship between music training and fluid intelligence when controlling for music aptitude. Conversely, there was a significant relationship between music aptitude and fluid intelligence when controlling for music training. Swaminathan et al. demonstrated that musical aptitude drives the relationship between musicality and fluid intelligence. Based on the moderation and mediation analyses, they consequently concluded that fluid intelligence and music aptitude is selective of who pursues and sticks with music training.

To summarize the literature reviewed above, the relationship between intelligence and musicality has largely been consistent in finding superior general intelligence and other lower-level abilities in musically-trained people compared to less trained people. However, a remaining concern is finding clear evidence of an increase in musicality causing a far-transfer enhancement of intelligence. Furthermore, a lack of uniformity in measuring musicality and sample diversity may impact the relationships found, similar to the working memory literature. For example, Swaminathan et al. (2017) primarily used psychology students; thus, the relationship between music lessons and fluid intelligence may become stronger by including experienced musicians pursuing a music-related degree in the sample. The growing number of studies in recent years investigating the topic of intelligence and musicality provides promise of a better understanding their relationship in the future.

Current Approach

The goals of the present study were to investigate the prediction of individual differences in working memory and fluid intelligence by measures of musicality. A major step in accomplishing these goals was to select measures for our variables of interest: working memory, fluid intelligence, and musicality. This step was critical because of the diverse range of approaches across studies investigating cognitive abilities and musicality. We chose measures that are valid, reliable, and consistent either across both the musicality and complex cognitive ability literatures or within its respective literature. Overall, we believe this investigation is comprehensive, with a broad range of complex cognitive tasks and musicality measures conducted on a musically-diverse sample.

Working Memory. We chose to use complex span tasks as our measures of working memory. These tasks are some of the most widely used working memory measures in cognitive psychology, have been proven to be reliable, valid measures, and consistently predict higher-order cognitive abilities (e.g., Conway et al., 2005). We were interested in measuring verbal, visuospatial, and tonal working memory. To limit domain or task specific effects, complex span tasks have analogous methodology across domains and require alternating between retaining a series of stimuli in serial order and proficiently completing a processing task. Theoretically, performance across complex tasks have reflected a domain-general view of working memory. (Kane et al., 2004). We consequently chose complex span tasks to explore relationships between working memory and musicality.

To our knowledge, a tonal complex span task has never been created. There is generally a lack of working memory measures that require the serial recall of a sequence of tones. This may be due to the difficulty for non-musicians to create representations of tonal pitches; thus, studies have used recognition paradigms potentially due to this obstacle. We created a tonal complex span task, Tonal span (Figure 1), by using the Operation span (Unsworth, Heitz, Schrock, & Engle 2005; Redick et al., 2012), which measures verbal working memory, as a blueprint. In Operation span, participants must memorize letters in serial order while completing a two-step math judgement before the presentation of each letter. After each trial, letters are recalled by making selections on a grid of possible letter choices. We replaced the letters with sine wave tones. An important goal for the creation of Tonal span was to create a measure of musical working memory that did not require musical skill. Thus, the selection and amount of tones used must not have inherent properties that are too difficult for a non-musician. We used the pitch-distal tone selection from Williamson, Baddeley, and Hitch (2010) in our Tonal span. Williamson et al. used a serial recall paradigm to measure short-term memory for tonal information in non-musicians and musicians. Three different tones were used in their paradigm. They were C4 (262 Hz), G4 (392 Hz), and B4 (494 Hz) and labeled low, middle, and high respectively on a grid for recall. Three tones were used because non-musicians had trouble discriminating four or more different tones in a series of pilot tests. According to Williamson et al., these tones were of similar tonal strength according to the Krumhansl tonal hierarchy theory (Krumhansl, 1990). Using tones of similar strength reduces tonality induction, which refers to the process of listeners developing expectations based on the music's key. However, these tones were based on the musical scale of C major, which could consequently still augment musician performance. Williamson et al. found that musicians outperformed non-musicians on their simple span measures of tonal short-term memory. Schulze et al. (2012) demonstrated that performance on tonal measures that require the retention and manipulation of tone sequences cannot simply be explained by knowledge of tonal structures. Therefore, the task-switching methodology of complex span tasks should theoretically provide limitations on knowledge of tonality that did not limit performance in Williamson et al., due to their use of a simple span measure.

We kept the same math processing task from Operation span in our Tonal span. This decision was justified by reviewing prior literature on the relationship between the to-be-remembered items and the processing task in a complex span task. For example, Turner and Engle (1989) extended work by Daneman and Carpenter (1980) that demonstrated that the nature of the processing task did not limit the predictive utility of complex span tasks to task-specific abilities. Daneman and Carpenter found that Reading span and its auditory analogue, Listening span, were related to performance on a series of reading comprehension tests. By examining qualitative differences in the types of reading errors made between high and low spans, they concluded that effective reading strategies by high spans provided an increase in capacity available for the to-be-remembered stimuli. Therefore, working memory capacity was viewed as a trade-off between both storage and processing functions. Turner and Engle (1989) extended their results by demonstrating that reading comprehension could be similarly predicted with mathematical operations in Operation span. By measuring quantitative math skills and removing their effects in their analytical approach, Turner and Engle showed that the correlations between Operation span and reading comprehension were similar to those found between Reading span and reading comprehension. Additionally, they manipulated the difficulty of the processing task of both Operation and Reading spans which, in result, reflected a functional relationship of the correlations between each task and reading comprehension. Thus, the important aspect of the processing task is that it is demanding enough to obtain individual differences in performance and impact general processing functions important to measuring working memory. The nature of the processing task in a working memory measure is independent of the working memory measure's ability to predict higher-order cognitive abilities.

However, Turner and Engle did not account for potential differences between processing tasks of different domains. An argument could be made that math operations are verbal in nature, due to the use of language to mentally compute the operations. Previous literature has demonstrated domain-specific effects of interference on tonal, verbal and visuospatial memories (e.g., Deutsch, 1970; Pechmann & Mohr, 1992; Logie, Zucco, & Baddeley, 1990; Shah &

Miyake, 1996). However, Vergauwe, Barrouillet, and Camos (2010) found that dual-task paradigms utilizing cross-domain interference decreased performance as a function of increasing cognitive load, regardless of domain. These results provided support for a domain-general view of working memory, despite potential domain-specific processing or rehearsal. Although Vergauwe et al. only used verbal and visuospatial stimuli and not tonal stimuli, the dual-task methodology of complex span tasks was designed to allow for individual difference comparisons and should results in Tonal span being an effective measure with a math processing manipulation.

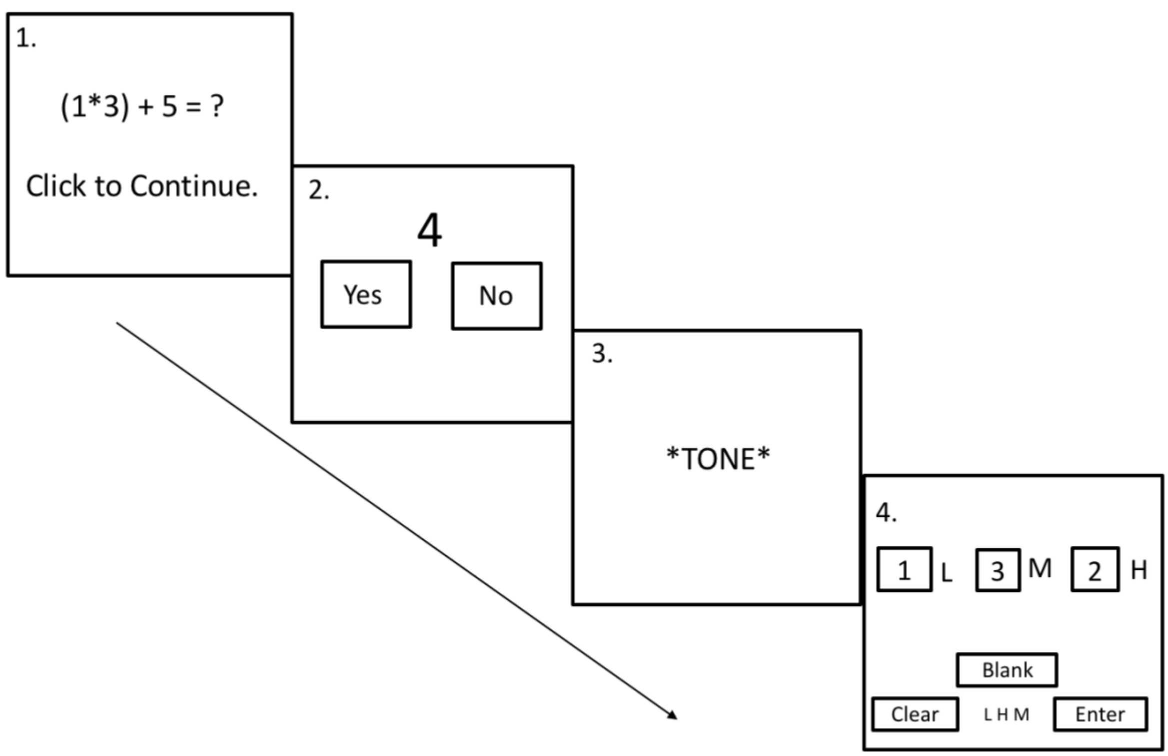

Figure 1. This is a trial simulation of Tonal span. Only one to-be-remembered item is shown in this figure, although the recall screen indicates recall of three tones. In Tonal span, a math operation is solved, and then a tone is played through headphones. At the end of each trial, the previously presented tones are recalled in serial order.

Fluid Intelligence. We used Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1998) as our measure of fluid intelligence. It is a widely-used task to measure individual differences in fluid intelligence, including in samples of college students (e.g., Carpenter, Just, & Shell, 1990), and it has been demonstrated to be related to measures of intellectual achievement and represent general, instead of task-specific, processes. This task is strongly related to higher-order complex tasks (e.g., Jensen, 1987), and working memory, including complex span tasks (e.g., Kane et al., 2004). Previous literature investigating the relationship between musicality and fluid intelligence have used Raven's as its measure of fluid intelligence (e.g., Slevc et al., 2016; Swaminathan et al., 2017). Therefore, direct comparisons between the magnitude of relationships were possible between previous literature and the current study's results, which promotes continuity and effective cross-study comparisons in the literature.

Musicality. The definitions of the terms "non-musician" and "musician' can be quite ambiguous, with inconsistent criteria being used to determine participant recruitment. Therefore, we recruited a musically-diverse sample of students ranging from undergraduate psychology students to doctoral music students. The Goldsmiths Musical Sophistication Index (Gold-MSI; Müllensiefen et al., 2014) was used to measure a broader construct of musicality, named "musical sophistication." Musical sophistication refers to a wide range of musical skills, expertise, achievements, and related behaviors. The Gold-MSI is not limited to measuring musicality in musically trained people; it can measure musicality in the general population with no formal training. Therefore, the Gold-MSI provided a comprehensive insight of the musical profiles of our musically-diverse sample.

The Gold-MSI measures musical sophistication through a self-report inventory comprising 38 questions that are used to compute composite scores of general musical sophistication and five subscales: musical ability, active engagement, perceptual abilities, singing abilities, and emotion. Six to nine questions underlie each sub-scale score. For example, questions about one's amount of regular daily practice, years of music theory training, hours practiced at their peak level of performance, and other related questions were used to calculate the musical ability subscale. 18 questions from the subscales are used to compute the general musical sophistication composite score (see Table 1). We were most interested in the composite score because it best represents the overall musical sophistication of each participant.

Additionally, the Gold-MSI provides objective, behavioral measures of beat perception, sound similarity, and melodic memory. These objective measures provide insight of participants' musical aptitude, in addition to their self-report answers on the Gold-MSI questionnaire. Using an internet sample of 147, 636 people, Müllensiefen et al. determined the Gold-MSI had internal consistency, test-rest reliability, and external validity with other musical self-report and auditory skill tests, such as the MET (Wallentin et al., 2010). We did not use sound similarity in our analyses to establish an analogous measurement comparison to other studies investigating musicality and cognitive abilities, specifically Slevc et al. (2016) and Swaminathan et al. (2017), which only incorporated musical memory and rhythmic subtests from the MET (Wallentin et al., 2010).

The overwhelming majority of studies measuring musicality have used years of formal training as a continuous variable or as criterion to separate a sample into two non-musician and musician groups. Therefore, we also used formal years of training as an additional variable of musicality to compare differences and similarities in the relationships found between musicality and cognitive abilities across measures. Although musicality assessments, such as the Gold-MSI, are more comprehensive, it is unclear whether they tap into unique relationships with complex cognitive skills. These comparisons will provide insight regarding task and sample-specific results.

Table 1. Questions for Gold-MSI Subscales and General Musical Sophistication

Subscale	*Question*
Active Engagement	Income spent on music
	Writing about music
	Music events attended
	Keeping track of new music
	Time spent listening to music
	Reading about music
	Free time spent on music activities
	Openness to unfamiliar music
	Addiction/Can't live without music
Perceptual Abilities	Judge other's singing ability
	Compare performances
	Judge other's beat performance
	Judge other's tonal performance
	Spotting mistakes in performance
	Recognizing familiar tune
	Recognizing novel tune
	Identifying genre
	Own tonal perception
Musical Training	**Regular daily practice**
	Number of instruments played
	Complimented on performance
	Number of hours practiced at peak
	Years of music theory training
	Years of instrument/vocal training
	Considers self a musician
Singing Abilities	**Sing back after hearing 2-3 times**
	Singing along correctly
	Sing in harmony to familiar tune
	Sing or play from memory
	Reluctant to sing in public
	Sing back hours later
	Ability to accompany novel tune
Emotions	**Identifying what is special**
	Communicating evoked emotions
	Use music to evoke emotions
	Pick music for shivers down spine
	Evoking memories
	Rarely evoking emotions

Note: Bolded questions are used for composite general musical sophistication score.

Hypotheses

The current study investigated the prediction of individual differences in working memory (verbal, visuospatial, and tonal) and fluid intelligence by measures of formal years of musical training, general musical sophistication, beat perception, and melodic memory. A musically-diverse sample of college students comprising non-musical and musical majors was recruited to access a wide variation of musical experiences, abilities, and training. We conducted exploratory correlation and regression analyses to compare how each individual musicality measure accounted for variation across the measures of working memory and fluid intelligence. This approach contributed to the literature by assessing the individual relationships between the musicality and complex cognitive measures. Additionally, using regression analyses, we were able to assess the relative contribution of an individual musicality measure, while controlling for the other musicality measures, towards performance on each complex cognitive task.

Among the working memory measures, we expected a general trend of tonal working memory performance having the strongest relationship with each musicality measure. Musicians have consistently outperformed non-musicians on tasks requiring the retention of tonal and atonal sequences (e.g., Williamson et al., 2010; Schulze et al., 2012). Superior musician performance compared to non-musicians has been inconsistent on verbal working memory tasks and was seldom shown in visuospatial working memory tasks. (e.g., Talamini et al., 2017). Therefore, we expected a general trend of visuospatial working memory to be the least related with musicality measures. These predictions are based on the musicality measures potentially being interrelated with each other and, in result, seeing similar trends between each musicality measure and working memory measure.

Among the musicality measures, we expected that performance on the melodic memory and beat perception tasks would have the strongest relationships with each working memory measure. The cognitive demands of the working memory tasks may cause individual variation in performance to be determined more by general cognitive ability than musical knowledge and experiences. The musical aptitude measures require a degree of general cognitive ability due to their task demands and, in result, may be able to best capture individual variation in working memory performance. We predicted that the memory demands in the melodic memory task would potentially have task-specific overlap with the working memory tasks, thus resulting in having the strongest relationship among all musicality measures. Thus, melodic memory and beat perception performance are the two most likely candidates to be most related to working memory performance, similar to results found in Slevc et al. (2016). We expected general musical sophistication and formal years of musical training's relationship with working memory performance would be similar, based on correlations found between the respective measures and the n-back tasks in Slevc et al, but lesser in magnitude compared to the aptitude measures.

We drew upon the results from Swaminathan et al. (2017) for our predictions of fluid intelligence. Similar to Swaminathan et al., we expected beat perception and melodic memory to be the most related to fluid intelligence among the musicality measures. Beat perception was expected to have the strongest relationship based on Swaminathan et al. and studies suggesting a relationship between sensory discrimination ability and intelligence (e.g., Deary et al., 2004; Troche & Rammsayer, 2009; Meyer, Hagmann-von Arx, Lemola, & Grob, 2010). General musical sophistication was expected to relate to fluid intelligence in a similar manner as formal years of training, due to their potential intercorrelations and similar relationships with other related complex cognitive tasks (e.g., Slevc et al., 2016).

CHAPTER 2. EXPERIMENT

Participants

Two hundred fifty-one students enrolled at Louisiana State University completed the study. We recruited students from the LSU community, mainly in the Department of Psychology and School of Music, with a purpose of obtaining a musically-diverse sample. The criteria for eligibility included being a native English speaker, reporting no hearing loss nor absolute pitch, and scoring at least 85% accuracy on the secondary tasks in all three complex span tasks. Five participants were not eligible due to being non-native English speakers. We did not use a participant's data if they were unable to complete the entire experiment; thus, four participants were not eligible due to computer malfunctions during at least one of the tasks. Forty-nine participants were not eligible due to not scoring at least 85% accuracy on the secondary tasks in at least one of the three complex span tasks (Operation span = 18; Symmetry span = 17; Tonal span = 9; Operation and Symmetry spans = 2; Symmetry and Tonal spans = 1; Operation, Symmetry, and Tonal spans = 2). Thus, one hundred and ninety-three participants met the criteria for inclusion. Participants volunteered, received course credit, or were paid $15.

The eligible participants were between the ages of 17 and 38 (M = 20.75, SD = 3.19). Participants' years of formal musical training was between 0 and 21 (M = 4.94, SD = 4.7). Ninety-one participants had more than four years of formal musical training (M = 9.03, SD = 3.41), and 102 participants had less than five years of formal musical training (M = 1.29, SD = 1.39). Participants' years of learning music theory was between 0 and 21 (M = 2.45, SD = 3.59). Participants' years of learning music theory and years of formal musical training were positively and significantly correlated (r = .67, p < .01). Forty-eight participants reported having a music-related major or minor.

Procedure

Participants completed eight tasks lasting approximately 90 min in an individual or group session. The tasks were the Gold-MSI self-report inventory, Tonal span, Symmetry span, Operation span, Gold-MSI beat perception test, Gold-MSI melodic memory test, Gold-MSI sound similarity test (not used in analyses), and the Raven's Advanced Progressive Matrices. All tasks were administered in the order listed above on a desktop computer. Sounds were presented at a comfortable listening level for tasks that required headphones. All participants provided informed consent and were debriefed.

Measures

Goldsmith's Musical Sophistication Index (Gold-MSI). Participants completed a 38-item self-report inventory on their musical skills, abilities, and behaviors. Questions consisted of free- response answers or choosing a selection on a Likert scale that ranged from 1-7. The answers were used to create a composite score of general musical sophistication and five subscales of active musical engagement, perceptual abilities, music training, singing abilities, and emotions (Müllensiefen et al., 2014).

Tonal span (TSPAN). In a modification of the OSPAN task, participants completed a two-step math operation and then tried to remember a tone presented through headphones (see Figure 1). In the math operation, participants saw an arithmetic problem (e.g., (4/4) – 1 = ?) and clicked the screen when they mentally solved the problem. Then, they were presented a digit on the next screen (e.g., 0) and had to click either the "true" or "false" box, depending on whether the presented answer matched the problem on the previous screen. A tone was presented through headphones for 1000ms after each math operation. The possible tones were C4 (262 Hz), G4 (392 Hz), and B4 (494 Hz) and were labeled low, middle, and high respectively (see Williamson et al., 2010, for a similar “pitch-distal” tone manipulation). During tone recall, participants saw a 1 X 3 matrix of all possible tones, each with its own box, following the response grid design implemented by Williamson et al. (2010). Tones were recalled in serial order by clicking on each tone’s box in the appropriate order. Tone recall was untimed. Participants were provided practice trials to practice distinguishing the tones and to become familiar with the procedure. The test procedure included three trials of each list length (3-7 tones), totaling 75 tones and 75 math operations. Strict serial position scoring was utilized, and the final score was the proportion of correct tones in the correct position. Based upon the convention in prior complex span literature, participants had to score at least 85% accuracy on the math operations to be included in analyses.

Symmetry span (SSPAN). Similar to the overall method of the TSPAN task, participants completed a two-step symmetry judgement and then tried to remember a visually-presented red square on a 4 X 4 matrix. In the symmetry judgment, participants were shown an 8 x 8 matrix with random squares filled in black. Participants had to decide if the black squares were symmetrical about the matrix’s vertical axis. When this judgement was made, participants clicked the screen. Next, they were shown a “yes” and “no” box on the next screen and clicked on the appropriate box for their answer. Participants then saw a 4 X 4 matrix for 650 ms with one red square after each symmetry judgement. During square recall, participants saw a blank 4X4 matrix and recalled the location of each red square by clicking on the appropriate cell in serial order. Participants were provided practice trials to become familiar with the procedure. The test procedure included three trials of each list length (2-5 red squares), totaling 42 squares and 42 symmetry judgements. The final score was the proportion of correctly recalled squares in regard to both location and order. The same inclusion criteria as Tonal span was used. This version of the task is from Unsworth et al. (2005).

Operation span (OSPAN). Participants completed a two-step math operation and then tried to remember a letter (F, H, J, K, L, N, P, Q, R, S, T, or Y) in an alternating sequence. The same math operation procedure as TSPAN was used. The letter was presented visually for 1000ms after each math operation. During letter recall, participants saw a 4 x 3 matrix of all possible letters, each with its own check box. Letters were recalled in serial order by clicking on each letter's box in the appropriate order. Letter recall was untimed. Participants were provided practice trials to become familiar with the procedure. Similar to TSPAN, the test procedure included three trials of each list length (3-7 letters), totaling 75 letters and 75 math operations. The same scoring procedure and inclusion criteria as TSPAN and SSPAN were used. This version of the task is from Unsworth et al. (2005).

Gold-MSI Beat Perception Test. Participants were presented 18 excerpts of instrumental music from rock, jazz, and classical genres (Müllensiefen et al., 2014). Each excerpt was presented for 10 to 16s through headphones and had a tempo ranging from 86 to 165 beats per minute. A metronomic beep was played over each excerpt either on or off the beat. Half of the excerpts had a beep on the beat, and the other half had a beep off the beat. After each excerpt was played, participants answered if the metronomic beep was on or off the beat and provided their confidence: I am sure, I am somewhat sure, or I am guessing. The final score was the proportion of correct responses.

Gold-MSI Melodic Memory Test. Participants were presented melodies between 10 to 17 notes long through headphones (Müllensiefen et al., 2014). There was a total of 12 trials. During each trial, two versions of a melody were presented. The second version was transposed to a different key. In half of the second version melodies, a note was changed a step up or down from its original position in the structure of the melody. After each trial, participants answered if the two melodies had identical pitch interval structures. The final score was the number of trials that were correctly judged.

Raven's Advanced Progressive Matrices (RAPM). Participants were presented a 3 x 3 matrix of geometric patterns with one pattern missing (Raven, Raven, & Court, 1998). Up to eight pattern choices were given at the bottom of the screen. Participants had to click the choice that correctly fit the pattern above. There were three blocks of 12 problems, totaling 36 problems. The items increased in difficulty across each block. A maximum of 5 min was allotted for each block, totaling 15 min. The final score was the total number of correct responses across the three blocks.

Results

We used a univariate outlier method of 3 standard deviations (*SD)* from the mean for each variable. One participant scored below 3 *SD* on RAPM and TSPAN. Two participants scored below 3 SD on OSPAN. Two participants scored below 2 SD on TSPAN. One participant had above 3 SD on formal years of musical training. Thus, a total of six participants were excluded (*N* = 187).

Descriptive statistics are shown in Table 2. All measures of interest in the analyses were approximately normally distributed with a skewness value less than 2 and kurtosis value less than 4 (Kline, 1998). Cronbach's coefficient alpha was computed for working memory and fluid intelligence measures as an index of internal consistency, for the current sample. Each were near or above 0.8, thus demonstrating high reliability. Working memory, fluid intelligence, and Gold-MSI descriptive statistics were similar to previously published research (e.g., Unsworth et al., 2009; Müllensiefen et al., 2014). The reliability statistics of the Gold-MSI measures were reported in the Müllensiefen et al. publication with acceptable levels of reliability.

Table 2. Descriptive Statistics

Measures	M	SD	Range	Skew	Kurtosis	Reliability
RAPM	24.78	4.62	14-36	-.05	-.60	.81
OSPAN	57.77	14.75	12-75	-1.26	1.11	.88
SSPAN	30.13	7.26	8-42	-.74	.31	.75
TSPAN	53.85	12.44	18-75	-.61	-.36	.83
BeatAc	.68	.14	.33-.89	-.10	-.72	.87*
MelodicAC	.64	.16	.23-1.00	-.12	.00	.61*
General	83.83	21.72	24-122	-.32	-.80	.93*
Musical	27.96	12.52	7-47	-.25	-1.24	.90*
Active	42.42	9.91	13-62	-.38	-.43	.87*
Perceptual	50.01	8.02	30-63	-.42	-.72	.87*
Singing	32.21	8.26	8-49	-.15	-.52	.87*
Emotion	35.10	4.71	14-42	-1.05	1.85	.79*
Age	20.72	3.20	17-38	2.61	9.36	-
FormalYrs	4.90	4.54	0-18	.71	-.39	-

Note: RAPM= Ravens; OSPAN = Operation span; SSPAN = Symmetry span; TSPAN = Tonal span; BeatAc = Beat perception accuracy; MelodicAc = Melodic memory accuracy; General = General musical sophistication; Musical = Musical ability; Active = Active musical engagement; Perceptual = Perceptual ability; Singing = Singing ability; Emotion = Emotional engagement with music; FormalYrs = Years of formal music training.
Reliability measured with Cronbach's alpha. * From Müllensiefen et al. (2014).

We used an alpha level of .05 to determine significance for all analyses. Correlations among all variables are shown in Table 3. Symmetry, Operation, and Tonal spans were all significantly and positively correlated with one another and fluid intelligence. Thus, construct validity was demonstrated with the tasks comprising the complex span construct correlating more strongly to one another than fluid intelligence (Campbell & Fiske, 1959). These results replicate previous findings in similar research (e.g., Unsworth et al., 2009), with an extension to Tonal span.

General musical sophistication was positively and significantly correlated with all five Gold-MSI subscales: musical ability, active engagement, perception, singing, and emotion. Beat perception and melodic memory accuracy were significantly correlated to one another and with general musical sophistication (r = .41 and r = .28 respectively). Thus, both objective and subjective measures from the Gold-MSI were validated, replicating similar findings in Müllensiefen et al. (2014). Formal years of musical training complemented the Gold-MSI with significant and positive correlations with general musical sophistication, beat perception, and melodic memory. Notably, formal years and general musical sophistication were highly correlated (*r* = .63). General musical sophistication, formal years of training, beat perception, and melodic memory are the musicality measures of interest and were focused on in the following reported analyses.

Correlations among the working memory and musicality measures demonstrated that Tonal span had the strongest relationship with each musicality measure. Additionally, Operation span had the weakest relationship with each musicality measure. In fact, Operation span had two nonsignificant relationships with beat perception and general musical sophistication, while all other relationships between each working memory and musicality measure were statistically significant. Among the musicality measures, Melodic memory had the strongest relationship with Operation and Symmetry spans and a strong relationship with Tonal Span. However, Tonal Span's strongest relationship was with general musical sophistication (*r* = .42), which was notably the strongest among all relational combinations of the musicality and cognitive measures of interest.

The magnitude of the correlations between Raven's Advanced Progressive Matrices (RAPM) and each musicality measure was larger than working memory, with the only exception being Tonal span. The correlation with the largest magnitude was RAPM with formal years of training, followed by beat perception. RAPM had similar relationships with general musical sophistication and melodic memory. All relationships between each musicality measure and RAPM were statistically significant.

Table 3. Bivariate Correlations Among Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
gF												
1. RAPM	-											
WM												
2. OSPAN	.30**	-										
3. SSPAN	.37**	.60**	-									
4. TSPAN	.40**	.55**	.58**	-								
GMSI-P												
5. BeatAC	.30**	.13	.16*	.27**	-							
6. MelodicAC	.23**	.18*	.23*	.33**	.16*	-						
GMSI-SR												
7. General	.24**	.10	.17*	.42**	.41**	.28**	-					
8. Musical	.29**	.11	.18*	.47**	.42**	.29**	.87**	-				
9. Active	.15*	.10	.08	.27**	.24**	.16*	.74**	.57**	-			
10. Percep	.22**	.05	.12	.26**	.32**	.24**	.81**	.66**	.57**	-		
11. Singing	.13	.11	.14	.32**	.29**	.21**	.86**	.63**	.52**	.71**	-	
12. Emotion	.15*	-.02	.02	.19**	.29**	.18*	.71**	.54**	.77**	.64**	.51**	-
13. FormalYrs	.33**	.16*	.18*	.36**	.36**	.25**	.63**	.79**	.43**	.52**	.47**	.39**

Note: *gF* = General fluid intelligence; RAPM= Ravens ;WM = Working memory; OSPAN = Operation span; SSPAN = Symmetry span; TSPAN = Tonal span; GMSI-P = Goldsmith musical sophistication index – perceptual; BeatAc = Beat perception accuracy; MelodicAc = Melodic memory accuracy; GMSI-SR = Goldsmith musical sophistication index – self report; General = General musical sophistication; Musical = Musical ability; Active = Active musical engagement; Percep = Perceptual ability; Singing = Singing ability; Emotion = Emotional engagement with music; FormalYrs = Formal years of musical training
** Correlation is significant at the .01 level (2-tailed) and * Correlation is significant at the .05 level (2-tailed).

While correlations provided information on the individual relationships between the musicality and complex cognitive measures, a regression approach allowed a deeper examination by assessing the relative contribution of an individual musicality measure towards performance on each complex cognitive task. Therefore, we conducted a series of simultaneous multiple regression analyses, using Operation span (OSPAN), Symmetry span (SSPAN), Tonal span (TSPAN), and Raven's Advanced Progressive Matrices (RAPM) as dependent variables. The independent variables were general musical sophistication, formal years of training, melodic memory, and beat perception.

We chose to use the simultaneous multiple regression approach due to the exploratory nature of the study's goals and not having expectations regarding the relationships between measures. The design of the experiment was not chosen to directly test causation (i.e., if musicality enhances complex cognitive abilities). It was chosen to extend Slevc et al. (2016) and Swaminathan et al. (2017), which both included simultaneous multiple regressions as part of their experimental designs. We were interested in determining if there is uniformity among musical measures in predicting complex cognitive abilities. Musicality is not monolithic and encompasses a diverse range of abilities of experiences. Therefore, understanding how each individual aspect of musicality related to complex cognitive skills provided a foundation of knowledge for future exploration regarding why their respective relationships occur and informed researchers about the potential influence of measurement and task selection on relationships. The statistical approach was useful to compare and contrast relationships between each individual musicality measure and performance on the complex cognitive tasks. We also utilized partial correlation analyses to determine each relationship while controlling for other musicality measures and squared semipartial correlation analyses to determine the unique contribution of each variable to a model. These coefficients help provide further information on if relationships are genuinely occurring between a musicality and complex cognitive measure and not as a byproduct of a different musicality measure.

We conducted a series of simultaneous multiple regression analyses (Tables 4-7), using Operation span (OSPAN), Symmetry span (SSPAN), Tonal span (TSPAN), and Raven's Advanced Progressive Matrices (RAPM) as dependent variables. The independent variables were general musical sophistication, formal years of training, melodic memory, and beat perception. A simultaneous multiple regression approach uses an "all in" method, in which all independent variables are input simultaneously and free from order.

The results of the regression models are shown in Tables 4-7. We assessed models by measuring R^2, adjusted R^2, the F statistic, and p value. We assessed an independent variable's contribution to the model by examining the beta weight, partial correlation, squared semipartial correlation, and the associated p value. Each model met the assumption requirements for simultaneous multiple regressions (Laerd Statistics, 2015). Independence of residuals was met with each model having a Durbin-Watson statistic near 2.0. There was homoscedasticity, which was determined by visually assessing a plot of studentized residuals versus unstandardized predicted values. There was no multicollinearity, which was determined by having a Tolerance value greater than 0.1 and a variance inflation factor (VIF) less than 10. General musical sophistication, formal years of musical training, melodic memory, and beat perception had Tolerance values of 0.555, 0.585, 0.913, and 0.815 respectively and VIFs of 1.801, 1.710, 1.095, and 1.227 respectively. Additionally, no correlations between independent variables were greater than 0.7 (see Table 2). As noted earlier in the descriptive statistics, each variable was normally distributed with skew and kurtosis values less than 4 and 2 respectively (Kline, 1998).

Table 4. Results of Simultaneous Multiple Regression: Tonal Span

Model	*ß*	*pr*	sr^2	*p*	*F*	R^2	$R^2_{adjusted}$	DW
MS	.245	.205	.033	.005				
Formal	.121	.106	.008	.153				
Melodic	.215	.230	.042	.002				
Beat	.094	.097	.007	.189				
Overall				<.001	14.571	.243	.226	1.752

Note: MS = General musical sophistication; Formal = Formal years of musical training; Melodic = Melodic memory; Beat = Beat perception; *pr* = partial correlation; sr^2 = semi partial correlation; DW = Durbin-Watson Statistic.

The results for the prediction of Tone span are shown in Table 4. The model accounted for 22.6% of the variance and was statistically significant. General musical sophistication and melodic memory performance were significant contributors, uniquely accounting for 3.3% and 4.2% of the variance respectively. Formal years of musical training and beat perception did not contribute to the model significantly and uniquely accounted for 0.8% and 0.7% of the variance respectively.

Table 5. Results of Simultaneous Multiple Regression: Symmetry Span

Model	*ß*	*pr*	sr^2	*p*	*F*	R^2	$R^2_{adjusted}$	DW
MS	.038	.029	.001	.691				
Formal	.082	.065	.004	.379				
Melodic	.184	.180	.031	.015				
Beat	.081	.075	.005	.309				
Overall				.006	3.731	.076	.055	1.886

Note: MS = General musical sophistication; Formal = Formal years of musical training; Melodic = Melodic memory; Beat = Beat perception; *pr* = partial correlation; sr^2 = semi partial correlation; DW = Durbin-Watson Statistic.

The results for the prediction of Symmetry span are shown in Table 5. The model accounted for approximately 5.5% of the variance and was statistically significant. Melodic memory was the only significant contributor, uniquely accounting for 3% of the variance.

General musical sophistication, formal years of musical training, and beat perception did not contribute to the model significantly and uniquely accounted for 0.1%, 0.4%, and 0.5% of the variance.

Table 6. Results of Simultaneous Multiple Regression: Operation Span

Model	*ß*	*pr*	sr^2	*p*	*F*	R^2	$R^2_{adjusted}$	DW
MS	-.047	-.036	.001	.627				
Formal	.123	.096	.009	.193				
Melodic	.154	.149	.022	.043				
Beat	.078	.073	.005	.328				
Overall				.041	2.551	.053	.032	1.873

Note: MS = General musical sophistication; Formal = Formal years of musical training; Melodic = Melodic memory; Beat = Beat perception; *pr* = partial correlation; sr^2 = semi partial correlation; DW = Durbin-Watson Statistic.

The results for the prediction of Operation span are shown in Table 6. The model accounted for approximately 3.2% of the variance and was statistically significant. Melodic memory was the only significant contributor, uniquely accounting for 2.2% of the variance. General musical sophistication, formal years of musical training, and beat perception did not contribute to the model significantly and uniquely accounted for 0.1%, 0.9%, and 0.5% of the variance.

Table 7. Results of Simultaneous Multiple Regression: Ravens Advanced Progressive Matrices

Model	*ß*	*pr*	sr^2	*p*	*F*	R^2	$R^2_{adjusted}$	DW
MS	-.045	-0.37	.001	.621				
Formal	.247	.203	.036	.006				
Melodic	.152	.157	.021	.033				
Beat	.202	.196	.033	.008				
Overall				<.001	9.088	.166	.148	2.184

Note: MS = General musical sophistication; Formal = Formal years of musical training; Melodic = Melodic memory; Beat = Beat perception; *pr* = partial correlation; sr^2 = semi partial correlation; DW = Durbin-Watson Statistic.

The results for the prediction of RAPM are shown in Table 7. The model accounted for 14.8% of the variance and was statistically significant. Formal years of musical training, beat perception, and melodic memory performance were significant contributors, uniquely accounting for 3.6%, 3.3%, and 2.1% of the variance respectively. General musical sophistication did not contribute to the model significantly and uniquely accounted for 0.1% of the variance respectively.

CHAPTER 3. GENERAL DISCUSSION

The present study was an individual differences exploration of the prediction of working memory and fluid intelligence by measures of musicality. The literature exploring the relationship between complex cognitive skills and musicality lacks consistency regarding sample selection and measurement methods. In result, findings across studies have conflicted in regard to statistical or theoretical conclusions. Consequently, we administered commonly utilized measures of working memory, in addition to a novel Tonal span task, fluid intelligence, and a comprehensive musicality assessment on a musically-diverse sample of college students across both musical and non-musical majors.

Working Memory

Both correlational and regression analyses clearly demonstrated that tonal working memory had a relationship with each musicality measure that was larger than verbal and visuospatial working memory. This result could be explained by a number of reasons. The methodology of Tonal span could have failed to fully limit advantageous domain-specific encoding processes by musical participants. The tones were based on a musical scale; thus, musical students could have used knowledge of tonality and other useful musical knowledge or skills to improve chunking and other rehearsal strategies. Schulze et al. (2012) demonstrated that musicians have superior tonal working memory for both tonal and atonal sequences that could not be explained by tonality knowledge in tasks that require both the maintenance and manipulation of stimuli. Theoretically, these results should extend to Tonal span, but not definitively. It is possible for performance on two different working memory paradigms to be related and be driven by different underlying process, such as complex span and change detection tasks (Shipstead, Redick, Hicks, & Engle, 2012). Alternatively, the inclusion of more than three unique tones may also challenge musical participants more than our current Tonal span design. A consequence of using three unique tones is that tones can repeat in trials due to list lengths being up to 7 items. This repetition does not occur in Operation or Symmetry spans. Using more than three unique tones could potentially cause non-musical participants to score at floor due to discrimination issues; thus, an experimental design manipulating the amount of unique tones would more than likely need to use a sample of only musical students. Future research should examine the relationship and underlying processes among tonal working memory measures using a number of methodological approaches.

Additionally, the processing task in Tonal span was not musical in nature. Research has demonstrated that tonal interference has a domain-specific influence on tonal memory (e.g., Deutsch, 1970; Pechmann & Mohr; 1992). Although individual differences in working memory performance are attainable with a cross-domain processing task (Vergauwe et al., 2010), a musical processing task could potentially lessen the variance explained by musicality through limiting both top-down and bottom-up musical processing. However, Tonal span had a similar relationship to fluid intelligence as Operation and Symmetry spans and demonstrated construct validity; therefore, the non-musical processing task did not limit its ability to relate to a higher-order cognitive ability. We believe the task effectively measured working memory due to these relationships but may not have obtained a pure measure of tonal working memory. This would have to be tested, however, by a follow-up study manipulating the tone selection and/or processing component with the previously suggested changes and comparing results with the current study.

Interestingly, both correlational and regression analyses showed a unique relationship between general musical sophistication and tonal working memory that was not found with verbal or visuospatial working memory. Also, formal years of musical training did not match their relationship in strength and was driven to non-significance in the multiple regression. This raises an interesting question of what strategies and skills are obtained by becoming more musically sophisticated that are beneficial towards our working memory for tones, beyond knowledge and skills acquired from formal training or aptitude. A follow-up study that examined strategies used by participants would help answer this question and also inform what improvements that Tonal span needs to be as effective as possible. Furthermore, an item-level examination on the relationship between each individual question that contributes to the general musical sophistication with Tonal span would help further understanding on what drives Tonal span performance.

The results regarding the relationship between verbal working memory and measures of musicality revealed that Operation span's variance was explained the least by musicality, according to the regression analysis. Additionally, it failed to reach statistical correlational significance with a number of musical measures and was the only complex span task to have non-significant relationships. Also, formal years of musical training had a stronger correlational relationship and contributed more to predicting verbal working memory than general musical sophistication. Similar to the tonal working memory results, this once again brings up the question of the musical skills and advantages that differentiate general musical sophistication from formal musical training and how they apply to various complex cognitive tasks. For example, non-significant correlational relationships were found between the visual letter n-back task and both musical sophistication and formal musical training in Slevc et al. (2016).

Unlike Operation span, Symmetry span did have significant correlational relationships with every musical measure. The differences in which musicality related to Operation and

Symmetry spans illustrates how different measurement selections of musicality can generate conflicting results in their relationship with working memory, despite the musical measures being potentially interrelated. That is, musicality measures can be strongly related to one another but differ in their prediction of complex cognitive skills. Additionally, there is a lack of theoretical knowledge regarding how and why each musicality measure underlies performance on complex cognitive tasks. Therefore, it is hard to conclude why these different relationships have occurred based on our study, but the inclusion of multiple measures of the constructs of musicality and working memory help to provide critical details that are needed to resolve these questions.

To our knowledge, Lee, Lu, and Ko (2007) and Franklin et al. (2008) were the only studies to have used complex span measures of working memory to assess the relationship between working memory and musicality in adults. Franklin et al. found significant differences between musicians and non-musicians on measures of Operation and Reading span. Lee, Lu, and Ko did not find significant differences between musicians and non-musicians on Operation span and a complex spatial span measure which was similar to Symmetry span used in the present study. Both studies compared musician and non-musician performance in a between-groups design and had a much smaller sample size in relation to the present study. Furthermore, the sample selection and measurement of musicality differed across the studies. Lee, Lu, and Ko used a participant demographic similar to our study but controlled for fluid intelligence. Franklin et al. also controlled for fluid intelligence, in addition to SAT scores, and recruited musicians using cutoffs for formal years of musical training, amount of continuous training, weekly practice hours, music education, and self-rated sight-reading skill. Additionally, we used separate variables of formal years of musical training and general musical sophistication in our analyses on a continuous scale. We did not control for fluid intelligence because of potential unintended consequences in limiting individual variation in working memory performance, due to working memory and fluid intelligence performance being strongly related (e.g., Kane et al., 2004). Therefore, it is difficult to compare our studies due to considerable differences in design.

The most consistent result across the regression analyses was the predictive relationship between melodic memory and each measure of working memory. The regression models for Operation and Symmetry spans were mainly driven by performance on melodic memory. Each musicality measure was non-significant in their regression models, except for melodic memory. Melodic melody was also a significant contributor to the prediction of tonal working memory and uniquely explained the most variance. These results may be due to the similarities of the melodic memory and working memory tasks. Slevc et al. (2016) also mentioned this issue. Both melodic memory and working memory measures require the retention and manipulation of a sequence of stimuli. Interestingly, beat perception was not a significant contributor in any working memory model, perhaps due to tapping more into attention and discrimination abilities than memory. Future studies should investigate how much performance on tests of melodic memory are explained by musical skills versus general cognitive abilities. For example, Meinz and Hambrick (2010) found that individual differences in working memory capacity predicted sight-reading ability in a sample of trained pianists, which could not be explained by their amount of personal, deliberate practice. Thus, there is potential for general cognitive abilities to contribute uniquely to the musical skills measured by melodic memory.

Fluid Intelligence

Our results provide a different insight compared to Swaminathan et al. (2017), who found that measures of music aptitude explained performance on a measure of fluid intelligence better than years of taking music lessons. Although they conducted a hierarchical multiple regression analysis, the first step in their regression approach is similar to ours, in which they conducted a simultaneous multiple regression. They found stronger partial correlations with beat perception and melodic memory than the amount of music lessons, which were parallel to later analyses determining that musical aptitude drove the relationship between musicality and fluid intelligence. However, our regression model showed that formal years of musical training contributed the most unique variance, in addition to beat perception and melodic memory contributing significantly to the model. These results conflict with Swaminathan et al., but a potential explanation may be sample selection. Our sample included students studying music in college, while they used only psychology students. They limited formal years of musical training to lessons outside of school, while our formal years of musical training variable included training in and outside of school. Furthermore, their non-musician recruitment was limited to students with less than two years of lessons outside of school. Thus, it is possible that these respective students could have received music lessons inside of school and, in result, have musicality. It is unclear if the nature that students obtained music lessons has an effect on the relationships found between musicality and complex cognitive skills.

It is also unclear exactly why, in the fluid intelligence regression, that formal years of musical training contributed the most to the model. This is in contrast to what was observed with Tonal span; we found that Tonal span was predicted by the general music sophistication score and melodic memory, whereas general fluid intelligence was predicted by formal years, and not musical sophistication, along with both melodic memory and beat perception. General musical sophistication contributed little to the prediction of verbal and visuospatial working memory, similar to the fluid intelligence regression. Thus, this result showed a pattern of little contribution by general musical sophistication regarding tasks without musically related stimuli. However, formal years of musical training contributed significantly to the fluid intelligence model, despite the fluid intelligence task not including musical stimuli. This may be reflective of earlier conclusions, in which the relationship between melodic memory and working memory tasks may be influenced by sharing task-specific methodology. Melodic memory captured a considerable amount of variance in each working memory model, which, in result, may take away from the variance captured by formal years of musical training. Beat perception uniquely explained more variance than melodic memory in the fluid intelligence model, which also contributes to the proposed task-specific methodology conclusion. Alternatively, these measures of musicality could tap into specific skills that underlie complex cognitive tasks differentially. These series of results demonstrated the potential of aspects of musicality relating differentially with complex cognitive tasks based on both theory and task selection. Furthermore, it illustrates why the research conducted in this study is helpful to begin clarifying these differences and promotes the usage of multiple methods to measuring both musicality and complex cognitive skills in future studies.

Final Remarks

The present study takes a step forward in understanding the specific relationships between measurements of musicality and complex cognitive skills. Musicality is multifaceted, and there is not one uniform way to measure musicality. Individual experiences with music are extremely diverse, which is reflective of our results. The critical takeaway from our study was that individual aspects of musicality relate to complex cognitive skills differentially from one another. We cannot conclude from our study definitively how and why these relationships occurred. To test causality, we would need to conduct a developmental study with an experimental design that includes random assignment of participants and an active control group. However, this study is a step towards examining these questions. Relationships could occur from sharing similar task-specific methodology or tapping into skillsets that underlie respective measures. Consequently, we suggest obtaining a comprehensive musical profile of each participant when assessing the relationship between musicality and cognitive abilities that is theoretically guided regarding the question of interest. Measuring musicality as one entity or construct, based on intercorrelations between musical measures, or only using one measurement tool, such as formal years of musical training, can potentially limit studies from learning how and why relationships between musicality and cognitive abilities occur. Furthermore, it is difficult to compare samples across studies due to limited demographic information provided by authors. Research on the relationship between musicality and cognitive abilities has both theoretical and practical significance, in terms of learning potential mechanisms for cognitive growth and the underpinnings of human cognition. Our study helps provide the foundation for further exploration on a wealth of related topics.

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APPENDIX. IRB EXEMPTION APPROVAL

ACTION ON EXEMPTION APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
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TO: Juan Ventura
Psychology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: February 16, 2016

RE: **IRB#** E9774

TITLE: The Generality of Working Memory: Does Music Training Enhance Working Memory Capacity?

New Protocol/Modification/Continuation: New Protocol

Review Date: 2/16/2016

Approved X **Disapproved** ______

Approval Date: 2/16/2016 **Approval Expiration Date:** 2/15/2019

Exemption Category/Paragraph: 1; 2a

Signed Consent Waived?: No

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable)

By: Dennis Landin, Chairman DLandin

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc. Approvals will automatically be closed by the IRB on the expiration date unless the PI requests a continuation.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

VITA

Juan Alexander Ventura received a Bachelor of Arts in Psychology from the University of North Carolina at Greensboro (UNCG) in 2014. At UNCG, Juan was a research assistant in the labs of Drs. Peter Delaney, Michael Kane, and Thomas Kwapil. He is currently a doctoral student at Louisiana State University in the Department of Psychology's Cognitive and Brain Sciences program. He is under the mentorship of Dr. Emily Elliott and plans to graduate with a Master of Arts in Psychology in August 2018.